THE FARM GATE CARBON AND WATER FOOTPRINT OF DIVERSE BEEF CATTLE GENOTYPES IN SOUTH AFRICA AND ITS ENVIRONMENTAL IMPACT

by

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The farm gate carbon and water footprint of diverse beef cattle genotypes in South Africa and its environmental impact

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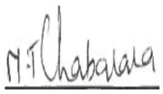

_____06 September 2023______

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Dedication

I dedicate this work to my family, especially my mother and partner for the continuous support throughout my struggles.

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First and foremost, I want to thank God Almighty for this wonderful and fortunate chance in my life.

My supervisor, Prof. M. M. Scholtz from the ARC-Animal Production, who continuously pursued his interest in encouraging me with my work and provided me with unwavering support and personal help, deserves a special note of gratitude and debt of gratitude.

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Abstract

The aim of this study is to estimate the current farm-gate carbon and blue water footprint of the major beef breeds in South Africa that is representative of the different breed types e.g. Sanga (indigenous), Sanga derived, Zebu, Zebu derived, British and European breeds. A simulation programme was used to simulate the methane production (expressed as methane intensity) and blue water footprint of a weaner calf production system for 9 diverse beef cattle genotypes. The chosen genotypes were based on the number of animals and the availability of data. The breeds involved were: Afrikaner, Nguni, Bonsmara, Angus, Hereford, Brahman, Brangus, Charolais and Simmentaler. The simulation study also involved a farm size of 1200 hectares (ha), with a carrying capacity of 6 hectares per Large Stock Unit (LSU) which could carry 200 LSU's. Frame size specific equations were used to estimate cow LSU units. The Tier 2 Intergovernmental Panel on Climate Change (IPCC) approach for the methane (CH_4) emission values, as already published in the literature was used. Through this approach it was estimated that the enteric methane emissions factor ($MEF_{enteric}$) of a LSU was equivalent/equal to 94kg methane/year. Furthermore, a 15% replacement rate, 2% pre-weaning mortality, 2% post weaning mortality and a 4% use of breeding bulls were assumed. The blue water use intensity can be estimated in the same way, and it was assumed that for every kg of dry matter intake, a ruminant animal needs 4 litres (L) of water, but it can be increased by 50 % when it is hot. Therefore, an average of 5 litres water intake was used. A LSU needs 9kg dry matter per day and therefore 45 litres of water per day. It was thus estimated that the litres of blue water consumed on the farm was 16 425 litres/year/LSU multiplied by 200 LSU's which was equal to 3 285 kilolitres. Actual published production values (weaning weight, cow weight, fertility) for each breed was used. For the small frame Afrikaner and Nguni breeds, it was estimated that the methane intensity (kg methane per kg live weight leaving the farm) was 0.60kg and 0.68 kg, respectively. For the medium frame Bonsmara, Angus, Hereford, Brahman and Brangus, the methane intensity was 0.59kg, 0.59kg, 0.64kg, 0.61kg and 0.62kg, respectively. Lastly, for the large frame Charolais and Simmentaler, the methane intensity was 0.85kg and 0.73kg, respectively. The methane intensity varied from 0.59kg CH_4 to 0.85kg CH_4, which represents a 44% difference. However, when comparing different size breeds, assuming a 10% improvement in each trait, the methane intensity varied from 0.55kg to 0.75kg, respectively and a 55% difference was then observed. Moreover, when estimating the water use intensity, it varied from 103 to 148 kilolitres from small to large frame breeds and when a 10% improvement was applied it then ranged from 96 to 131 kilolitres per kg live weight leaving the farm. It was surprising that the Nguni had a medium methane and water intensity, since it is the most fertile breed. However, it should be taken into account that the Nguni was the smallest breed and 147 cows with calves could be kept on the 1 200ha farm. These cows and calves produce large quantities of methane and utilizes large/high water quantities as compared to some of the other breeds. The Afrikaner, Bonsmara, Angus, Brahman and Brangus breeds have low methane and water use intensities and can be regarded as environmentally friendly. The Nguni and Hereford breeds have medium methane and water use intensities while the Charolais and Simmentaler breeds have higher methane and water use intensities. This information can be used to develop a model that can estimate the farm-gate methane emission and water use intensity for different breed types, production levels and systems. Such a model will be valuable in the event that carbon taxes are introduced and total life cycle of water use can be fully analysed.

Xianakanyiwa

Xikongomelo xa phurojeke leyi i ku pima khaboni ya sweswi ya farm-gate na mati ya blue water footprint ya tinxaka letikulu ta nyama ya homu e Afrika Dzonga leswi yimelaka tinxaka to hambana ta tinxaka xikombiso Sanga (indigenous), Sanga derived, Zebu, Zebu derived, British na Tinxaka ta le Yuropa. Dyondzo yitirhisiwile ku tekelela vuhumelerisi bya methane (leswi kombisiwaka tani hi matimba ya methane) na blue water footprint ya weaner calf production system eka 9 wa ti genotypes to hambana hambana ta tihomu ta homu. Ti genotypes leti hlawuriweke ati seketeriwile eka nhlayo ya swifuwo xikan'we naku kumeka ka data. Tinxaka leti katsekaka akuri: Afrikaner, Nguni, Bonsmara, Angus, Hereford, Brahman, Brangus, Charolais na Simmentaler. Dyondzo ya simulation yitlhele yi katsa vukulu bya purasi ra 1200 wa ti hectares (ha), laha kungana vuswikoti byo rhwala bya 6 wa ti hectares hi Large Stock Unit (LSU) leyinga rhwala 200 wa ti LSU's. Kutani ku tirhisiwile ti equations to hlawuleka ta vukulu bya furemu ku ringanyeta tiyuniti ta LSU ta tihomu. Endlelo ra Tier 2 ra Phanele ya le Xikarhi ka Mfumo eka ku Cinca ka Maxelo (IPCC) eka mimpimo ya ku humesiwa ka methane (CH_4), tanihilaha se swi kandziyisiweke hakona eka matsalwa. Hiku tirhisa endlelo leri ku ringanyetiwe leswaku enteric methane emissions factor ($MEF_{enteric}$) ya LSU ayi ringana/ringana na 94kg methane/lembe. Kuya emahlweni, 15% wa nhlayo ya ku cinciwa, 2% wa ku fa ka le mahlweni ka ku lumuriwa, 2% wa ku fa endzhaku ka ku lumuriwa na 4% wa ku tirhisiwa ka tinkunzi leti fuyiwaka swi tekiwile. Kutala ka matirhiselo ya mati ya wasi yanga ringanyetiwa hindlela leyi fanaka, naswona aku ehleketiwile leswaku eka kg yin'wana na yin'wana ya swakudya swo oma leswi dyiwaka xifuwo lexi dyaka swilava 4 wa tilitara (L) ta mati, kambe xinga engeteriwa hi 50 % loko xi hisa. Hikokwalaho, ku tirhisiwile xiringaniso xa 5 wa tilitara ta mati lawa ya dyiwaka. LSU yilava 9kg ya swakudya swo oma hi siku naswona hikokwalaho ka sweswo 45 wa tilitara ta mati hi siku. Xisweswo swiringanyetiwile leswaku tilitara ta mati ya wasi lawa ya tirhisiwaka e purasini akuri 16 425 wa tilitara/lembe/LSU ku andzisiwa hi 200 wa ti LSU leswi ringanaka na 3 285 wa tikhilolitara. Mimpimo ya xiviri ya vuhumelerisi leyi kandziyisiweke (ndzilo wa ku lumuriwa, ntiko wa tihomu, ku veleka) eka muxaka wun'wana na wun'wana wutirhisiwile. Eka tinxaka letintsongo ta frame, Afrikaner na Nguni, aku ringanyetiwa leswaku matimba ya methane (kg methane hi kg ya ntiko lowu hanyaka lowu humaka

e purasini) akuri 0.60kg na 0.68 kg, hiku landzelelana. Eka furemu yale xikarhi, ya Bonsmara, Angus, Hereford, Brahman, Brangus, matimba ya methane akuri 0.59kg, 0.59kg, 0.64kg, 0.61kg, 0.62kg, hiku landzelelana. Naswona eka furemu leyikulu, Charolais na Simmentaler, matimba ya methane akuri 0.85kg na 0.73kg, hiku landzelelana. Nhlayo ya methane ayi hambana kusuka eka 0.59kg CH4 kuya eka 0.85kg CH4, leswi yimelaka ku hambana ka 44%. Hambiswiritano, loko ku pimanyisiwa tinxaka tohambana hambana ta vukulu, hiku tekela enhlokweni ku cinca ka 10% eka mfanelo yin'wana na yin'wana, matimba ya methane ya hambana kusuka eka 0.55kg kuya eka 0.75kg, hiku landzelelana. Naswona kwalomu ka 55% wa ku hambana ku tlhele ku voniwa. Ku tlula kwalaho, loko ku ringanyetiwa matimba ya matirhiselo ya mati, ya hambana kusuka eka 103 kuya eka 148 kilolitres kusuka eka tinxaka letintsongo kuya eka letikulu ta furemu naswona loko 10% wa ku cinca ku cheriwa kutani akuri kusuka eka 96 kuya eka 131 kilolitres hi ntiko lowu hanyaka lowu humaka e purasini. A swi hlamarisa kuva va Nguni ayiri na methane yale xikarhi xikan'we na mati yotala, tani hileswi kunga muxaka lowu noneke swinene. Hambiswiritano, swifanele ku tekeriwa enhlokweni leswaku Nguni akuri muxaka lowuntsongo swinene naswona 147 wa tihomu letingana marhole tinga hlayisiwa eka purasi ra 1 200ha. Tihomu leti na marhole ya humesa nhlayo leyikulu ya methane naswona ya tirhisa mati lamakulu/yale henhla loko ku pimanyisiwa na tinxaka ta Afrikaner, Bonsmara, Angus, Brahman na Brangus. Tinxaka ta Afrikaner, Bonsmara, Angus, Brahman na Brangus tina methane yale hansi na matirhiselo ya mati naswona tinga tekiwa tani hi letinga onhi mbango. Tinxaka ta Nguni na Hereford tina methane yale xikarhi xikan'we na matirhiselo ya mati kasi tinxaka ta Charolais na Simmentaler tina methane yale henhla xikan'we na matirhiselo ya mati. Mahungu lawa yanga tirhisiwa ku tumbuluxa modele lowu nga ringanyetaka ku humesiwa ka methane ya le purasini xikan'we na matimba ya matirhiselo ya mati eka tinxaka tohambana hambana ta tinxaka, swiyimo swa vuhumelerisi na tisisiteme. Modele wo tano wu ta va wa nkoka loko ko tshuka ku nghenisiwa swibalo swa khaboni naswona xirhendzevutani xa vutomi hinkwabyo xa matirhiselo ya mati xi ta xopaxopiwa hi ku hetiseka.

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Chapter 1: General Introduction

1.1 Background

It must be recognized that ruminants are important to humans, as most of the world's plant biomass is high in fibre. Only ruminants can convert high-fibre vegetation into high-quality protein sources (such as meat and milk) for human consumption, and this must be balanced with the concomitant methane production (Scholtz *et al.,* 2013).

While Hoekstra (2003) defines the water footprint as the amount of fresh water used to produce the product, measured over the various steps of the production chain, McMichael *et al.* (2007) define carbon footprint (CF) as the total greenhouse gas (GHG) emissions caused by individuals, events, organizations, services, or products, and is expressed as carbon dioxide equivalent (CO_2e).

Beef cattle produce large amounts of greenhouse gases (GHG) (Steinfeld *et al*., 2006) and are often accused of using large amounts of water in beef production (Meissner *et al.,* 2012). Some assumptions used to calculate the carbon or water footprint of beef products are questionable.

Scholtz *et al.* (2013) states that in developed countries the GHG emissions from agriculture are less than 6% because of the huge contribution from the other sectors involved. In non-industrial countries, the relative contribution of agriculture could be 40%-50%, while in developed countries the actual contribution could be well below 6%. When considering mitigation options, it is clear that reducing greenhouse gas emissions by 10% from the energy and mining sectors is much more effective than reducing agriculture's 5-10% contribution by 10%. The proposed "meat-free once a week" argument doesn't really solve the problem. This is because human consumption requires other protein sources and can even lead to a high carbon footprint (Meissner *et al.,* 2012).

Scollan *et al.* (2010) cites a study claiming a water requirement of 15,500 litres per kilogram of beef, and he assumed it would take three years to produce 200 kilograms of boneless beef. The estimate only accounts for 155L of water for drinking, cleaning, and post-farm gate activities, with the remainder used to produce feed for livestock, water for crop production, and rainfall on the property. A study using more realistic and rational assumptions found much lower water requirements for red meat production (Peters *et al*., 2010).

The media often reports alarming figures on the greenhouse gas emissions and water use of farm animals. Without putting the methods and context of the calculations into perspective, many consumers have developed the perception that meat consumption is harmful to the environment. However, it is important to consider the wider context of ruminant production under extensive conditions. This study will attempt to present a balanced perspective on the carbon and blue water footprint of primary beef production in South Africa.

1.2. Study motivation

Differences in production systems between countries and regions affect the carbon and water footprint of animal products. Current methods for estimating these footprints are largely based on dubious assumptions based on northern hemisphere countries, which do not have distinct production systems such as those found in southern Africa.

Livestock are the world's largest users of land resources, and South Africa is no exception. About 84% of the area in South Africa is available for agriculture. However, most of it is unsuitable for crop production, with around 13% being arable land. Most of South Africa (about 71%) is only suitable for large-scale / extensive livestock farming (RMRD SA, 2012).

Research and development on climate change and greenhouse gases is critical to the sustainable use of South Africa's natural resources for beef production. In Africa, subsistence farmers also keep livestock for various purposes and many rural households depend on livestock for milk, meat, hides, horns, fertilizer, and income (Chimonyo *et al*., 1999; Dovie *et al*., 2006), which is the main source of livelihood and welfare for rural communities.

Capper (2011) compared beef production from 1977 to 2007 in the United States of America, which showed that modern beef production requires significantly fewer resources and has a lower environmental impact. This study showed that improving productivity is the key to reducing the environmental impact of beef production.

By quantifying the carbon and water footprints of South Africa's major cattle breeds and their environmental impacts, government can develop emission standards for the Agriculture, Forestry and Other Land Use (AFOLU) sectors, which can provide information to be used in their efforts for developing baselines values. Environmental protection is one area where livestock, especially beef cattle, is being scrutinized, as many consumers consider beef production to have unacceptable environmental costs.

An excellent combination of resources in eco-friendly beef production i.e. animal science is essential, in which academics, researchers and companies must combine their efforts. This information will be useful for extrapolation to future climate change scenarios, especially projected temperature increases and humidity scenarios, which should support the development of adaptive technologies (or demonstrate timely acceptance of alternative land uses) to address climate change. Thus, the industry will have new effective and sustainable tools to contribute to climate-smart agriculture. Consequently, this will play an important role in the socioeconomic activities of communities and helps livestock farmers to develop mitigation strategies to deal with climate change.

1.3. Aim and Objectives

1.3.1. Aim

The aim of this study is to estimate the current farm-gate carbon and blue water footprint for 9 diverse beef cattle genotypes in South Africa that are representatives of the different breed types. The genotypes were chosen on the numbers of animals and the availability of data. The breeds involved were, Sanga (Afrikaner and Nguni), Sanga derived (Bonsmara), Zebu (Brahman), Zebu derived (Brangus), British (Angus and Hereford) and European (Charolais and Simmentaler), respectively. The information resulting from this study can be used by the Department of Environment Affairs in their effort to develop an emissions baseline for the Agriculture, Forestry and Other Land Use (AFOLU) sectors, which will be especially important if a carbon tax is to be introduced.

1.3.2. Specific objectives

- To quantify the effect of breed type and weaning percentage on the farm-gate carbon footprint of beef production.
- To quantify the effects of breed type and weaning percentage on the farm-gate blue water footprint of beef production.
- To quantify the effect of a 10% change in each of the component traits (calf weaning weight, cow weight, and fertility) on the environmental impact of beef production.

1.4. Hypotheses

The study hypothesised that:

- There will be no difference of the effect of breed type and weaning percentage on the farm-gate carbon footprint of beef production.
- There will be no difference of the effects of breed type and weaning percentage on the farm-gate blue water footprint of beef production.
- There will be no difference of the effect of a 10% change in each of the component traits (calf weaning weight, cow weight, and fertility) on the environmental impact.

1.5. Relevance of the study

The scientific outputs of this study will play an important role in the socio-economic activities of the communities by assisting beef cattle farmers to adopt mitigation strategies to cope with climate change. As such, it will contribute to sustainable rural livelihoods, ensuring food security, economic growth and development.

1.6. Research outputs

1.6.1 Below are the scientific outputs of this study thus far:

- Chabalala, N.T., Scholtz, M.M. & Grobler, S.M. The blue water footprint of primary beef production systems in South Africa. Proceedings 51st SASAS congress, 10 – 12 June 2019, Bloemfontein (oral)
- Chabalala, N.T., Scholtz, M.M. & Grobler, S.M., 2019. Perspective on the methane production of primary beef production systems in South Africa. Proceedings 7th Greenhouse Gas and Animal Agriculture Conference, 4 – 8 August 2019, Iguassu Falls, Brazil (Poster)
- Chabalala, N.T., Scholtz, M.M. & Pyoos-Daniels, G.M., 2019. Perspective on the methane production of primary beef production systems in South Africa. Proceedings of the Agricultural Research Council 6th annual post graduate conference, Roodeplaat, 6 – 9 October 2019 (oral)
- Chabalala, N.T., Chadyiwa M.C., Scholtz, M.M. & Mapholi, N.O., 2021. The carbon footprint of diverse beef cattle genotypes in South Africa and its environmental impact. Proceedings 52nd SASAS congress, 10-12 August 2021, virtual Microsoft teams (oral)
- Scholtz, M.M., Jordaan, F.J., Chabalala, N.T., Pyoos, G.M., Mamabolo, M.J. & Neser, F.W.C., 2023. A balanced perspective on the contribution of extensive ruminant production to greenhouse gas emissions in southern Africa. African Journal of Range & Forage Science, 40:1, 107-113.

1.7. Chapter outline

Chapter 1 will address the study background, scope and what the study is intending to achieve. **Chapter 2** will give the broader understanding of the study by the support of the literature from previous related research, while **Chapter 3** will be unpacking the methodology which was applied to execute the study. **Chapters 4, 5 and 6** will present the results and discussions of the different research findings respectively. Lastly, **Chapter 7** will give a broad conclusion on the findings of the study and provide possible recommendations for further or future research to be considered.

Chapter 2: Literature Review

2.1 Introduction

Beef production systems can be broadly categorized as extensive, which includes, rangeland, mixed and intensive farming. Large-scale beef production systems usually include feedlots, as well as cow-calf and Ox production (Greenwood, 2021). According to FAOSTAT (2020), there are 1.5 billion cattle worldwide. By 2023, 74 million tonnes of beef will be consumed globally, up from 70 million tonnes in 2019. After poultry and pork, beef was the third most consumed food in 2019. A record-breaking 18% of the beef produced in 2019 was exported.

The primary beef producing countries or regions include the United States (17% of global beef production), Europe (15%), Brazil (13%), China (9%), Argentina (4%), India (4%) and Australia (4%) (Greenwood, 2021). Livestock products are becoming more and more in demand worldwide (OECD/FAO, 2018). This is brought about by the growing population as well as the requirement for high-quality protein in diets, especially in developing countries. The use of animal products has increased as economies have grown (WHO, 2020). According to Rotz (2020), the effects on the environment differ significantly based on the production methods and climate.

A total 356 million cattle are in Africa, of which 44 million were killed in 2018 to produce 6.7 million tonnes of meat (FAOSTAT, 2020). Sub-Saharan Africa includes 700 million hectares of grasslands between the tropics of Cancer and Capricorn, and is home to the majority of African cattle (Otte *et al*., 2019). Ethiopia (63 million head), Sudan (31 million), Chad (29 million), Tanzania (27 million), Nigeria (21 million), and Kenya (20 million) are the African countries with the biggest herds of cattle.

Higher on-farm productivity and efficiency can result from improved nutrition, management, and health in unconventional systems, including those in South Africa (Visser *et al*., 2020; Oduniyi *et al*., 2020), which are more in line with higher performing production systems elsewhere in the globe. Though access to export markets is restricted due to health concerns, certain African nations, such as South Africa, Botswana, and Namibia, export small amounts of beef.

The majority of concerns about livestock products environmental impact have been centered on greenhouse gas (GHG) emissions. There are a number of mitigation techniques being considered to lower emissions in the production of cattle, such as improved feeding efficiency, enteric methane inhibitors, anaerobic manure digestion, and reduction of manure storage (Rotz, 2022). Moreover, a 50% reduction in the feedlot phase results in only a small 3% reduction in the total emissions of cattle production, as feedlot finishing only accounts for approximately 14% of the life cycle emissions. In a paper cited by Putman *et al.* (2023), mitigation is more challenging during the cow-calf phase, when cows are kept on pasture and rangeland, whereas reductions during this phase would have a higher positive impact.

Water usage poses a danger to the long-term viability of animal production (Rotz, 2020). According to estimates from around the world, agriculture uses 70% of freshwater withdrawals, with 20% going toward producing feed for livestock (FAO, 2018). Mekonnen and Hoekstra (2016), explained that four billion people worldwide experienced serious water scarcity in 2016. Furthermore, Mosase *et al.* (2019) also indicated that the population growth is predicted to cause water scarcity to worsen. Given that the agricultural industry depends heavily on large volumes of water, this is a serious concern. Most months of the year already see moderate to severe water scarcity in South African river basins (Zhuo *et al*., 2019; Rosa *et al*., 2020). With the exception of the Komati and Maputo river basins, which are primarily supported by sugarcane plantations, fodder crops account for the majority of the blue water footprint. Thus, a thorough literature analysis was conducted to examine the entire life cycle of South Africa's carbon and water footprints.

2.2 Beef production in South Africa

South Africa currently produces 21.4% of all meat produced on the African continent and just 1% of global meat production (RMRD SA, 2016). With the livestock industry accounting for 34.1% of gross domestic agricultural production and meeting 36% of the population's protein needs, the red meat industry must pay more attention to output rather than just the quality aspect of production. It is logical to arrive at a point where the focus is not only on the biological and technical aspects that affect meat quality characteristics (RMRD SA, 2016), but also on the environmental impact.

In South Africa, beef cattle is slaughtered at a much younger age (14 - 18 months) than international standards, which makes it one of the healthiest sources of beef in the world, low in cholesterol and fat (USDA Global Agricultural Information Network, 2015).

South Africa has approximately 13.4 million cattle (DAFF, 2016). Of these, about 60% are owned by commercial farmers and 40% by emerging and communal farmers, with about 100 feedlots and 431 slaughterhouses (DAFF, 2016). In addition, most of the breed types in the emerging and communal sectors are Nguni (35%), Brahman (32%), Bonsmara (17%), and Afrikaner (8%) (NERPO, 2000; Scholtz *et al. al*., 2008). This is mainly due to ease of handling, adaptability and fewer parturition issues.

Livestock are the largest users of land and resources, and South Africa is no exception. About 84% of the area in South Africa is available for agriculture. However, only 13% is arable. Most of South Africa (about 71%) is suitable only for large-scale livestock farming (RMRD SA, 2016), with most livestock production happening on natural rangelands.

The calf portion of the production cycle accounts for 72% of nutritional needs from conception to slaughter (Ferrell & Jenkins, 1982). Although primary farming (cow-to-calf production cycle) of beef cattle is extensively practiced in South Africa, more than 75% of cattle slaughtered in the formal sector are finished on maize and maize by-products through fattening in feedlots (RMRD SA, 2016).

Ferrell & Jenkins (1982) indicated that if we can reduce the energy required to feed cattle, less energy will be required for feed, which will reduce cattle input costs and increase cattle efficiency. The combination of increased productivity and reduced energy use should lead to a reduction in greenhouse gas emissions per unit of product. It is, therefore, clear that the cow and calf production cycle should be the starting point if there is a need to reduce the carbon and water footprint.

The relationship between cow weight and calf weaning weight was already examined at the start of performance recording. Most of the costs of the cow and calf production systems are related to cattle care and production requirements where calf weight is the standard output of such systems. In addition, Vanmiddlesworth *et al*. (1977) proposed further research on the calf-to-cow weight ratio as a measure of 'total cattle productivity'.

2.3. The South African breeds

The regulations of the Animal Improvement Act of South Africa (Act No 62 of 1998) indicates that South Africa has 34 recognised beef breeds. For the purposes of this study, the breeds were categorised according to Sanga, Sanga derived, Zebu, Zebu derived, the British and the European breeds respectively. A brief description of the breeds is presented below and was derived from Scholtz (2010). It should be noted that this information on the summary of the breeds will form part of a mobile phone App that the ARC is in the process of developing.

2.3.1. The Afrikaner

Figure 2.1: Afrikaner cows and calves (Source, ARC)

The **Afrikaner** breed is among the oldest indigenous breeds in South Africa and its history is closely associated with the history of the country and its people. It was developed from cattle originating from the tribes of Koi (Hottentot/San) people that owned them during 17th and 18th centuries (Epstein, 1956). The Afrikaner Cattle Breeders' Society was one of the first breed societies to be established in South Africa, being founded in 1912. A recent study (Makina *et al.,* 2016) confirmed that there is very little evidence of *Bos indicus* (Zebu) in the modern day Afrikaner and that it can be described as a taurine tropical adapted breed (Sanga), which makes it fairly unique.

The small to medium size of the Afrikaner cow, with its longevity, moderate maintenance requirements, and mothering ability makes it the ideal dam line for the production of heavy weaners when mated to large frame bulls. Its adaptation to adverse environments and resilience to climatic influences makes it the breed of choice for climate-smart beef production in extensive beef production areas.

2.3.2. The Nguni

Figure 2.2: Nguni cow and calf (source, ARC)

The Sanga cattle originally found along the east coast of Southern Africa are known as the **Nguni**, and they were found wherever the original African Nguni tribes settled (Swaziland, Zululand: is one of the 11 District Municipality of the KwaZulu-Natal province of South Africa, Mozambique, Zimbabwe) during their migration to Southern Africa between 600 and 1400 AD (Scholtz, 2010). Since then, these animals have played an important social and economic role in the development of these people. Nguni cattle are known for their fertility, resistance to diseases, and adaptability to punitive climates (Scholtz, 2010a). It should be noted that less than 20% of registered Nguni cattle are subjected to performance recording. Although there is no such thing as a universal breed, the Nguni has found its way to almost every livestock production region in South Africa over the years. The breed is selected on functional efficiency and breed characteristics, while maintaining its inherent traits. It is an adapted, low maintenance, breed that will ensure sustainable, economic beef production in South Africa in the face of global warming.

2.3.3. The Bonsmara

Figure 2.3: Bonsmara cow and calf (Source, ARC)

The **Bonsmara** is a breed of cattle known for its high quality beef. It originated in South Africa as a scientific experiment of Professor Jan Bonsma conducted at the Mara and Mesina Research stations (South Africa), from 1937 to 1963. The Bonsmara was created after many cross mating's and back-crosses and had an approximate breed composition of five-eighths Afrikaner (Sanga-type), three-sixteenths Hereford and three-sixteenths Shorthorn (both taurine types) (Maule, 1990). The Bonsmara is functionally efficient, well adapted to extensive production in Southern Africa, as well as the harsh climatic conditions. They are very fertile with small to medium size calves for easy calving, while producing a calf that is sought after by the feedlot industry (Scholtz, 2010). The Bonsmara became world-renowned as the first beef cattle breed which was created through a crossbreeding programme with the aid of objectively recorded performance data. The Bonsmara SA Society was founded in 1964 (Bonsmara SA, 2018). The breed has expanded within the borders of South Africa to be the most prominent beef cattle breed. The breed has also been accepted by other African countries such as Namibia, Mozambique, Uganda and Zambia; and in the beef cattle industries of Argentina, Australia, Brazil, Paraguay, Colombia, USA and Uruguay, since 1995, where it is expanding at a fast rate in an industry with more than 300 million beef cattle.

2.3.4. The Angus

Figure 2.4: Black Angus cow and calf (Source, ARC)

The **Angus** originated in Scotland in the 16th century and is the only breed that has been bred specifically for the quality of its beef since the earliest times. The first Angus cattle were introduced in South Africa in 1895, when ten head arrived on the farm of Mr J Newbury, in the Free State. The Angus Society of South is one of the oldest breeders' societies and was founded in 1917. The Angus breed is characterised by good growth, excellent mothering abilities, functional udders, adaptability, good temperament, early marketability and a global gene pool. Other unique qualities include polledness, medium-frame size, easy calving and small birth weights, combined with beef of outstanding flavour, juiciness and tenderness (Scholtz, 2010). These are contributing factors for the growth of the Angus breed world-wide, as reported at the 2009 World Forum in Canada. This explains why the Angus is the most numerous British beef breed in South Africa. The Angus Society of South Africa was the first society to market branded beef through the "Certified South African Angus Beef" project. The marketing process includes feedlots, abattoirs, the restaurant industry, selected butcheries and the Pick n Pay supermarket group.

2.3.5. The Hereford

Figure 2.5: A herd of Hereford cows (Source, ARC)

The **Hereford** was introduced to South Africa during 1892 with the importation of two bulls from England. During 1903 a further 27 cows and four bulls were imported by the Transvaal Government and were largely responsible for fostering interest in this breed. The Hereford Breeder's Society of South Africa was founded in 1917. The Hereford can be polled or horned, they are early maturing, highly fertile (with one of the shortest inter-calving periods of the major beef breeds in South Africa) and have the ability to convert low-quality forage into high-quality, high-yielding meat. Herefords have juicy and flavourful beef with sufficient marbling (Scholtz, 2010). Herefords are adapted to perform under adverse climatic conditions and are therefore present throughout South Africa. They cross especially well with Zebu cattle for the warmer climates and with Angus for more moderate climates.

2.3.6. The Brahman

Figure 2.6: A Brahman bull (Source, ARC)

The **Brahman** is an American breed of zebu-taurine hybrid beef cattle. The introduction of the Brahman to Southern Africa occurred in 1954 when Mr Jurgen Crantz of Namibia, imported 8 males and 10 females from Texas. Three years later, a meeting of 13 persons founded the Brahman Cattle Breeders' Society of South Africa at Kroonstad in the Free State. The Brahman can be summarized as, economic efficient, long marketing period since it qualifies for A and AB classes up to 32 months, longevity, parasite resistance, hardiness, adaptability, mothering ability, calving ease and hybrid vigour. Over the past six decades, the Brahman has dramatically changed the composition of the national commercial herd in this country. The reason for this is its ability to cross well with any other breed of cattle. In addition, the breed's versatility allows it to perform well in an environment that changes frequently, due to unforeseen climatic conditions.

2.3.7. The Brangus

Figure 2.7: A Brangus bull, cow and calf (Source, ARC)

Based on Brahman and Angus cattle, the **Brangus** was first developed in the USA in the 1940's. In Australia the breed developed between 1950 and 1960 by selection and development of progeny from crossing Angus cows and Brahman bulls in the coastal tropical areas of Queensland. The proportion of each breed varies from one-quarter to three-quarters Brahman and the remainder Angus. The Brangus was developed specifically to utilize the superior traits of Brahman and Angus cattle (adaptability, mothering ability, calving ease). In planned crossbreeding programmes these two breeds are probably more complementary to each other than any other two breeds. In 1986, the South African Breeders' Society was established (Scholtz, 2010). The Brangus is a good forager, and the cows make excellent mothers with an ample supply of milk. Their ability to do well in the hot areas and their resistance to ticks are important attributes.

2.3.8. The Charolais

Figure 2.8: A Charolais cow and calf (Source, ARC)

The **Charolais** has its origin in the Bresse-Plateau Region in the Jura Mountains of Eastern France. The Charolais breed is large-framed, long-bodied, heavily muscled and late-maturing. Most Charolais are horned, though some polled animals are now being bred. Docility is one of their features. The breed yields heavy, well-muscled, fine-textured and lean carcasses. At first small exports occurred, with for example, one bull and three cows exported to South Africa in 1955 followed by three bulls and 15 females in 1956 (Scholtz, 2010). As the breed demonstrated adaptability and outstanding results in the new territories into which it had then been introduced, it was exported all over the world and the Charolais breed is proving its worth on a global scale in more than 70 countries. Today the Charolais is well adapted to South African conditions and has already made a significant contribution to the improvement of the country's beef production, especially through crossbreeding (Hugenoot breed).

2.3.9. The Simmentaler

Figure 2.9: A Simmentaler cow and calf (Source, ARC)

The sustained popularity of the Simmentaler in southern Africa is because the breed is successfully used in crossbreeding to produce cows with high milk production and/or fast growing weaners/steers. The bull is the most important investment in the herd. Utilization of the Simmentaler EBV and pedigree certificate reduces this investment risk. Buyers should always insist on the certificate when buying a bull (Scholtz, 2010). The name Simmentaler is derived from the valley of the Simmerom River in Switzerland from where the breed originated. It is a descendant of the Aurochs (*Bos taurus primigenius),* the indigenous cattle of Europe. The low "genetic relatedness" of the Simmentaler with Zebu, Sanga and British breeds makes it the ideal breed for crossbreeding.

2.4. The carbon footprint

Livestock farming in South Africa is based on a unique combination of commercial (intensive and extensive) and emerging / communal (subsistence) production systems. Productivity and efficiency levels between these two major production systems differ significantly in certain areas, and it is important to distinguish between them when calculating GHG emissions (Du Toit *et al.,* 2013).

Livestock are unique in that they are not only affected by climate change, but also contribute to it through greenhouse gas emissions (Scholtz *et al.,* 2013b). The effects of global warming and the continued uncontrolled release GHG have a double impact on livestock production and consequent food security. Firstly, the continued increase in ambient temperature has implications not only for animals, but also for food and nutritional safety, due to variations associated with changes in the temperature itself, relative humidity, precipitation distribution in time and space. Consequently, is expected to have a direct impact on disease distribution, changes in ecosystems and biome composition. Secondly, the livestock industry has a responsibility to limit its GHG emissions or carbon footprint to ensure livestock's sustainability (Scholtz *et al.,* 2013a).

Livestock emissions are the largest source (98%) of CH_4 emissions from agriculture (Otter, 2010). Blignaut *et al*. (2005) states that livestock accounts for 14% of all CH_4 emissions in South Africa. Livestock farming releases nitrous oxide (N_2O) and CH_4 through the management of manure, as well as CH_4, which is directly produced by the animals. Manure storage and land use, which result in emissions of CH_4 and N_2O, and feed crop production, which results in emissions of N_2O and carbon dioxide (CO_2), are additional sources of GHG emissions linked to the production of beef (Desjardins *et al.,* 2012). Methanogenesis is influenced by several factors, including feed intake, feed composition, feed digestibility and quality, feed type and variety, and inter-animal variability (Scholtz *et al.,* 2012).

Beef production, one of the largest industries in the agricultural sector, is a significant contributor to GHG emissions. The main source is a process known as enteric fermentation, in which large amounts of CH_4 are produced and released from the microbial breakdown of feed in the animal's forestomach.

Desjardins *et al*. (2012) further explained that the carbon footprint for beef cattle should be expressed in a common functional unit, such as one kg of live weight (LW), or as the weight of the animal at the farm-gate, as it will be done in this study. The IPCC (2006) methodology underlies the carbon footprint estimation. It relies on a tiered system based on the availability of emission factors linked to activity data. Tier I is based on standard empirical emission factors published by the IPCC (2006) and is the simplest approach available. Tier II is still empirical in nature, as emission factors are usually derived from country-specific experimental data (Rochette *et al.,* 2008). Tier III is the most complex method and relies on the process-based model (Smith, 2004).

Desjardins *et al.* (2012) showed that moving to higher-level estimates is considered good practice, since CH_4 emissions are the main factor affecting carbon footprint in cattle. Cattle are reported to account for 55% (Verge, 2008) and 92% (Ridoutt *et al*., 2011) of carbon footprint, with the majority of CH_4 excretion due to enteric fermentation. The FAO (2009) showed that climate change is a feedback loop, with livestock production contributing to the problem and suffering from the consequences. The effects of global warming and continued attribution of GHG emissions to livestock are rising temperatures, which will have a negative impact on food security, safety, and productivity. Therefore, livestock production will need to limit its carbon footprint to ensure future sustainability.

The latter will be crucial if South Africa is to meet the 2030 goals of the Paris Agreement. The goal of limiting global temperature rise to +1.5°C will not be met unless GHG emissions are reduced with 35% by 2030 (FAO, 2009). An effective way to reduce the carbon footprint of beef production and support climate-friendly production is to reduce the number of cows and increase the production per cow. Increased productivity reduces GHG emissions per unit of product (Scholtz *et al*., 2014). In contrast to the production systems of temperate countries in the Northern Hemisphere, maximum production may not be the most realistic or appropriate goal in the context of southern Africa (Mokolobate, 2015).

If calf weaning weight relative to cow body weight can be increased and fertility can be improved (if calving intervals can be shortened), cow productivity (and, therefore, the environmental impact) will be improved. Jordan (2015) cited by Scholtz *et al*., (2016) indicated that in the Afrikaner, an 18.3% increase in cow-calf productivity had a significant environmental impact due to a 12% decrease in $MEF^{enteric}$ (enteric methane emission factor.

Mokolobate (2015) points out that production efficiency in South African cattle is improved by increasing calf weaning weight relative to Large Stock Units (LSU) of cattle in calf production systems, since LSU is an estimate of feed intake required to sustain cows and calves. This new measure of cow performance can be used to estimate cow productivity by relating it to the frequency of calf production, as indicated by the inter-calving period (ICP).

Jordaan (2015) estimated that changes in the Afrikaner improved cattle productivity over a period of 33 years. He found that weaning weight increased by 20 kg, cow weight decreased by 8 kg, and ICP decreased by 20 days. These changes helped in improving cattle productivity by 18.3%. In South Africa, the enteric methane emission factor ($MEF^{enteric}$), defined as kg methane/year of a LSU was estimated to be 94 kg/year for beef cattle (Du toit *et al.,* 2013). From this value, the $MEF^{enteric}$ for Afrikaner was estimated to be 1 kg per kg of calves weaned in 1980 and decreased to 0.88 kg $MEF^{enteric}$ in 2013 (a 12% decrease). Increased cattle productivity promotes sustainable production with a lower environmental impact.

2.5. The water footprint

As the tension between animal production and water use is increasingly recognized, it is important to understand the distribution and need for freshwater in animal production (Ridout *et al.,* 2014). Lamastra *et al.* (2014) and Hoekstra & Chapagain (2008) classified the water footprint into three types. The blue water footprint relates to runoff water stored in rivers, dams, or underground aquifers. The green water footprint refers to the amount of water that evaporates from the world's green water resources (rainwater stored in soil). The Grey water footprint, which measures the amount of polluted water, is quantified as the amount of water required to dilute the pollutants in the water to such an extent that the ambient water quality exceeds the agreed water quality standards. The latter mainly refers to grey water from feedlots and abattoirs.

Instead of just focusing on the total water footprint as a volume value, it is important to look at the green, blue and grey components separately to see what each water footprint component is (D'Silva and Webster, 2010). According to Bennie & Hensley (2001), agriculture consumes 74.5% of South Africa's precipitation. Of this, 60% is used for natural vegetation, 12% for dryland cultivation and 2.5% for irrigation. Blue water used for livestock in large systems comes primarily from groundwater sources, either runoff from streams, dams or underground aquifers that can be used for other forms of production, industry, or people. Chapagain & Hoekstra (2004) calculated that agriculture accounts for 86% of global water use. Most of it is rainwater and is used for crop production. But the focus is not only about total water, but also about water use and water resources, and the competing demands of industries, humans and agriculture (Chapagain & Hoekstra, 2004).

It should be noted that only green water is used for natural vegetation and crop production on dry land. It is used by plants growing in soil, meaning that it is only used for natural vegetation and crop production on dry land, and not for any other purpose (Hoekstra *et al*., 2011; Molden., 2013). In large-scale grazing systems, natural vegetation, the feed source for livestock, uses only green water. These large grazing systems are often located in areas unsuitable for crop production due to inadequate rainfall and poor soils. Therefore, the amount of water used per animal product production (e.g. 1 kg of meat) on extensive grazing or natural pastures is irrelevant in calculating water consumption for beef production. Natural pastures not used for livestock or hunting lead to wasted water. Regarding food production, green water can only be used for the production of meat and other animal products under large-scale grazing systems on natural pastures, like in South Africa. These systems are important for regional food security that prevails in nearly all developing countries. Natural rangelands in these areas do not use blue water (SIWI, IFPRI, IUCN, IWMI, 2005; Falkenmark & Rockström, 2006).

This is quite different from the centralized systems in Europe and North America. Rainwater only soaks into the ground, so there is no water cost for pasture production.

There is little the farmer can do to capture this water, except than making sure there is dense vegetation, managing the rangeland properly to prevent damaging flooding and erosion, and silting the dikes to prevent excessive runoff past the farm gate. Water use efficiency in slaughterhouses and processing plants, appears to be used inefficiently and wasted (Meissner *et al*., 2012). This includes wastewater from feedlots, slaughterhouses and dairy farms.

2.6 Conclusion

Chapter 2 provided a comprehensive literature review for the study. The literature explores different production systems that can affect the estimation of both the carbon and water footprint of beef. The importance of livestock and the ability to transform plants into high-quality meals (dairy and meat) that humans consume every day, should be acknowledged.

The social aspects and economic importance of the available agricultural land (84%) in South Africa is addressed, and it is pointed out that 70% of the available land is being used for extensive livestock farming and 12% is being used for dryland crop production. The remaining 2% is used for irrigation. It should be noted that most towns in urban areas are dependent on the money these ranchers spend.

A DAFF report (2016) shows the important role livestock plays in South Africa, with 38,000 farms in the commercial sector employing about 250,000 people and an additional 1.5 million direct dependents. On the other hand, in the emerging and communal sector, about 1.4 million households are engaged in livestock farming with another 10 million dependents.

An effective way to reduce the carbon footprint of beef production and support climate-friendly production is to have fewer cows and more production per cow. Increased productivity reduces GHG emissions per unit of product. Therefore, it is increasingly important to define breeding goals and develop appropriate selection criteria and crossbreeding strategies to ensure that beef production is effective and aimed at sustainable production in a changing environment (Scholtz *et al.,* 2014).

The different water footprint categories are highlighted and distinction is made between the different types of water used. This is categorized in rainwater (green water footprint), surface and groundwater (blue water footprint), and fresh water required to dilute polluted water to ambient water quality standards (grey water footprint). For example, the water footprint also shows the sources of water used to produce food and takes into account the impact of pollution on freshwater resources. It should be noted that livestock such as beef cattle are associated with income, livelihood, employment, fertilizer, energy, social and cultural functions.

Chapter 3: Materials and Methods

3.1 Data Collection and Large Stock Units

Data from 1,289,227 animals for a 10 years period (1999-2008) for cow weight (CW; n = 397 848), weaning weight (WW; n = 493 531) and inter-calving period (ICP; n = 397 848) was used in a simulation study to estimate the carbon and water footprint of beef production in South Africa (Table 3.1). The breed statistics are presented in Chapter 4 as part of the results.

In this study, the carbon and water footprint of the following breeds as described in the literature review were simulated:

- Afrikaner and Nguni (Sanga)
- Bonsmara (Sanga derived)
- Brahman (Zebu)
- Brangus (Zebu derived)
- Angus and Hereford (British breed)
- Simmentaler and Charolais (European breed)

The carbon and blue water footprint of a weaner calf production system was estimated, using the calf and cow weights; as well as the ICP for each of the 9 breeds.

Information from Meissner (1983) was used to developed frame size specific equations to estimate the LSU's for beef cattle in South Africa (Mokolobate, 2015). A farm size of 1200 hectares (ha) with a carrying capacity of 6 ha/LSU was simulated, this farm could carry 200 LSU/s.

Table 3.1: Genotypes and the number (n) of records for a 10-year period on which the national averages were based on.

Genotypes	**Cow weight (n)**	**Weaning weight (n)**	**Inter-calving period (n)**
Afrikaner	22 662	19 446	22 662
Nguni	51 785	15 282	51 785
Bonsmara	226 445	266 880	226 445
Brahman	3 640	3 970	3 640
Angus	31 731	28 673	31 731
Brangus	Not available	73 148	Not available
Hereford	14 964	13 660	14 964
Charolais	13 220	14 189	13 220
Simmentaler	33 401	58 283	33 401
Total	**397 848**	**493 531**	**397 848**

3.1.1. Carbon footprint simulation data

Estimates of carbon footprint were based on Du Toit *et al*. (2013), who followed the Intergovernmental Panel on Climate Change (IPCC) tier 2 approach. Through this approach it was estimated that the enteric methane emissions factor ($MEF^{enteric}$) of a Large Stock Unit (LSU) was 94kg methane/year. In addition the following assumptions were made:

- Cow replacement percentage: 15%
- Pre-weaning mortality: 3%
- Post weaning mortality: 2%
- Percentage bulls used: 4%

3.1.2. Water footprint simulation data

The blue water footprint of beef was estimated using LSU as the reference. A general guideline for water intake is that for every kg of dry matter intake a ruminant animal needs 4 litres of water, but it can be increased by 50% when it is hot (Wagner and

Eagle, 2021). Therefore, an average of 5 litres of water was used. A LSU consumes 9kg dry matter per day and therefore 45 litres of water per day.

3.1.3. Data Management

A quantitative study was conducted using the published data obtained from the South African Integrated Registration and Genetic Information System (INTERGIS), which stores all data from the National Beef Recording and Improvement Scheme, as summarized by Scholtz (2010). Data from this scheme is collected according to approved standard operating procedures and is accredited with the International Committee for Animal Recording (ICAR).

The National Beef Recording and Improvement Scheme consists of six phases. The information used in this study was collected through Phases A1 and A2 of the scheme. In Phase A1 all calves birth dates (including abortions and still born calves) and the identity number of dams were recorded. From the birth dates of the calves, the inter-calving period (ICP) for the cows were calculated. In Phase A2 the weaning weight of the calf and the cow weight was recorded. The weaning weight of the calf must be recorded, and the age range for when it was taken was between 151 and 250 days. These actual weaning weights are then converted to a standard weaning weight at 205 days of age. It is not compulsory to record the cow weight at weaning of her calf, but the majority of farmers do record it (Scholtz, 2010).

3.2 Data analysis

3.2.1 Frame size regression equations:

The Agricultural Research Council (ARC) has developed regression equations for the different frame sizes: i.e. small, medium and large frame; and physiological stages (lactating cow, replacement heifer, weaner calf, breeding bull, etc.). These were developed for different body weights and they can be used to calculate individual and total herd LSU's for specific herd compositions (Mokolobate, *et al.,* 2015). Table 3.2 shows an example of the LSU equivalents for beef cattle of different frame sizes for cows with calves (weaner production system). It is important to note that the LSU equivalent of cows with the same body weight, but different frame sizes, differs. Furthermore, the relationship between cow weight and LSU is not linear.

Table 3.2: LSU equivalents for beef cattle of different frame sizes of cows with calves (Adapted from Mokolobate *et al.,* 2015)

Cow weight (kg)	**Frame size**		
	Small	**Medium**	**Large**
250	0.89	X	X
275	0.95	X	X
300	1.00	1.05	X
325	1.06	1.11	X
350	1.11	1.17	X
375	1.16	1.23	1.48
400	1.22	1.29	1.55
425	1.27	1.34	1.61
450	1.32	1.40	1.66
475	1.37	1.45	1.72
500	1.42	1.50	1.78
525	1.47	1.55	1.83
550	1.52	1.60	1.88
575	1.57	1.65	1.93
600	1.61	1.69	1.98
625	X	1.74	2.02
650	X	1.78	2.07
675	X	X	2.11

The following equations were used for the estimation of LSU's for different frame sizes (Mokolobate, *et al.,* 2015):

a) Small frame $Y = 0.2871428571 + 0.0025542857*X - 0.0000005714*X^2$ ($P < 0.01$)

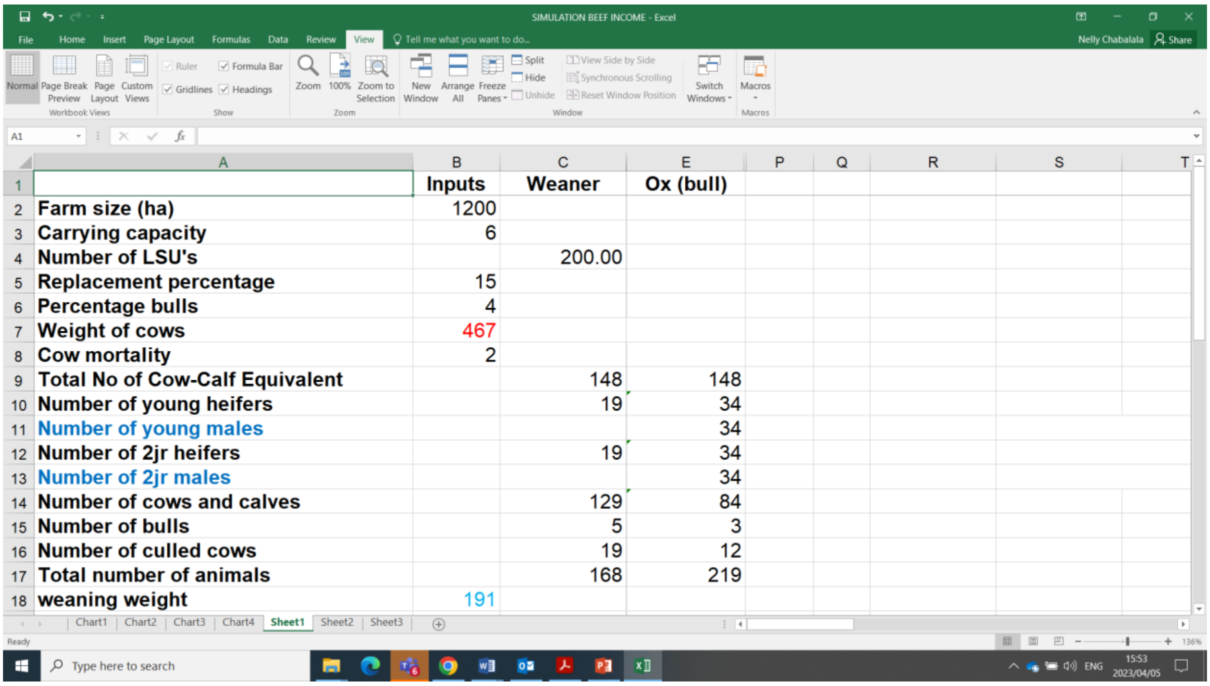
b) Medium frame $Y = 0.220714286 + 0.0030978571*X - 0.0000010714*X^2$ ($P < 0.01$)

c) Large Frame $Y = 0.3239285714 + 0.0036535717*X - 0.0000015*X^2$ ($P < 0.01$)

Where Y = LSU and X = cow weight

Simulation programme:

Neser (2012) has developed a generalized simulation program to estimate outputs from different systems and breed types. This program was adapted to include different frame sizes, where after a simulation study was conducted to estimate the carbon and water footprint of farm-gate (primary) beef production.



	A	B	C	E
1		Inputs	Weaner	Ox (bull)
2	Farm size (ha)	1200		
3	Carrying capacity	6		
4	Number of LSU's		200.00	
5	Replacement percentage	15		
6	Percentage bulls	4		
7	Weight of cows	467		
8	Cow mortality	2		
9	Total No of Cow-Calf Equivalent		148	148
10	Number of young heifers		19	34
11	Number of young males			34
12	Number of 2jr heifers		19	34
13	Number of 2jr males			34
14	Number of cows and calves		129	84
15	Number of bulls		5	3
16	Number of culled cows		19	12
17	Total number of animals		168	219
18	weaning weight	191		

Figure 3.1: Example of the information that is used in the simulation programme.

Meissner *et al.,* (1983) describes a Large Stock Unit (LSU) in South Africa as an equivalent of an ox with a live weight of 450kg, which gains 500g per day on grass pasture that has a mean Digestible Energy (DE) of 55%, with maintenance requires 75 Megajoule (MJ) per day of Metabolized Energy (ME). Only the weaner production system was simulated in this study. In the example in Figure 3.1 a farm size of 1200ha was simulated using an Afrikaner breed (small frame) as an example with a carrying capacity of 6 LSU's, 467kg cow weight, 4% of bulls, 15% replacement rate, mortality rate of 2% and a 191kg weaning weight were applied. Thus, the farm can carry 148 cows with calves in the weaner production system.

Calving percentage (%):

The predicted calving percentage (%) was calculated according to Roux and Scholtz (1984) using the following equation:

$$\text{Calving percentage} = 100 - \frac{\text{(Average inter calving period per year} - \text{365 days)}}{\text{365 days}} \times 100$$

3.4. Ethical considerations

The study was carried out following the strict rules and regulations of the University of South Africa Animal Ethics Committee. Ethical clearance was acquired from the University of South Africa (**22/CAES_AREC/062**) before the commencement of the study. It should be noted that the Agricultural Research Council – Animal Production, Irene, South Africa ethics committee does not provide ethical clearance for the use of secondary data, since the data used for this study is available in the public domain.

3.5. Notes on terminology

In this study the methane emissions was estimated as the methane intensity, which is the total annual CH_4 emissions from the farm (18 800kg CH_4) / total sellable live weight. This was also converted to the carbon dioxide equivalent for comparison with literature information. In the discussion, the term carbon footprint will be used when referring to methane emissions. Likewise, the term blue water footprint will refer to the kilolitres (kl) of water needed to produce 1 kilogram (kg) of live weight leaving the farm.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 The breed statistics of methane

The breed statistics are presented in **Table 4.1.** The Afrikaner and Nguni represent the small frame breeds (in dark blue), the Bonsmara, Angus, Hereford, Brahman and Brangus represent the medium frame breeds (in green) and the Charolais and Simmentaler represents the large frame breeds (in light blue), respectively.

Table 4.1: Breed statistics used to estimate methane

Genotypes	Cow Weight (kg)	205-day calf weight (kg)	Inter-calving period (days)	Estimated Calving Percentage (%)	Weaning Percentage (%)
Breed 1 -Afrikaner	467	191	448	77	75
Breed 2 – Nguni	367	155	404	89	87
Breed 3 - Bonsmara	503	217	414	87	84
Breed 4 – Angus	515	219	419	85	82
Breed 5 - Hereford	540	204	398	91	88
Breed 6- Brahman	520	214	455	73	71
Breed 7 - Brangus	488	203	450	77	75
Breed 8 - Charolais	630	232	430	82	80
Breed 9 - Simmentaler	553	241	474	70	68

4.2 The herd statistics for the estimation of methane

The herd statistics for the different breeds was estimated with the simulation program and the number of animals per category are presented in **Table 4.2**. From **Table 4.2** the number of animals available for disposal was calculated by adding the number of culled cows and the number of calves available for sale. The numbers also reflect the number of heifer weaner calves that must be retained to replace the 15 % culled cows that must be replaced annually.

Table 4.2: The herd statistics used to estimate methane

Genotypes	Number of cows with calves (n)	Number of culled cows (n)	2-year old heifers (n)	1-year old heifers (n)	Number of Bulls (n)	Number of calves to sell (n)
Breed 1 – Afrikaner	135	20	20	20	5	115
Breed 2 – Nguni	147	22	22	22	6	125
Breed 3 - Bonsmara	123	18	18	18	5	105
Breed 4 – Angus	120	18	18	18	5	102
Breed 5 – Hereford	115	17	17	17	5	98
Breed 6- Brahman	119	18	18	18	5	101
Breed 7 – Brangus	126	18	19	19	5	107
Breed 8 – Charolais	77	11	11	11	3	66
Breed 9 - Simmentaler	90	13	13	13	4	77

4.3 Methane calculations

The total CH_4 production from the farm per year (Tier II) was estimated as follows:

200LSU's x 94kg CH_4 = 18 800kg CH_4.

The information needed to calculate the CH_4 intensity and CH_4 intensity for the different breeds are also presented in **Table 4.3.** The CH_4 intensity was estimated as follows: Methane intensity = total annual CH_4 emissions from the farm (18 800kg CH_4) / total sellable live weight.

Table 4.3: The information needed to calculate the methane intensity and the methane intensity calculations

Genotypes	Number of weaner calf surplus (n)	Weaning weight (kg)	Total weight of weaner calf (kg)	Number of culled cows (n)	Cow weight (kg)	Total weight of culled cows (kg)	Total weight/ live weight off farm (kg)	Methane Intensity ($KgCH_4$/kg live weight)
Breed 1 – Afrikaner	115	191	21 965	20	467	9 340	31 305	0.60
Breed 2 – Nguni	125	155	19 375	22	367	8 074	27 499	0.68
Breed 3 – Bonsmara	105	217	22 785	18	503	9 054	31 839	0.59
Breed 4 – Angus	102	219	22 338	18	515	9 270	31 608	0.59
Breed 5 – Hereford	98	204	19 992	17	540	9 180	29 172	0.64
Breed 6- Brahman	101	214	21 614	18	520	9 360	30 974	0.61
Breed 7 – Brangus	107	203	21 721	18	488	8 784	30 505	0.62
Breed 8 – Charolais	66	232	15 312	11	630	6 930	22 242	0.85
Breed 9 – Simmentaler	77	241	18 557	13	553	7 189	25 746	0.73

In the case of the Afrikaner, for example, the total kg of weaner calves available for sale is 115 calves x 191 kg weaning weight = 21 965 kg of weaner calves. Likewise, the total kg of culled cows was calculated as 9 340 kg (20 cows x 467 kg). The total kg live weight that can leave the farm is, therefore, 31 305kg (21 965 + 9 340). In the case of the Afrikaner the CH_4 intensity (kg CH_4 / kg live weight leaving the farm) was 18 800kg CH_4 / 31 305kg, which was equal to 0.60kg.

From **Table 4.3** it can be seen that the CH_4 intensity varies from 0.59kg for the Bonsmara and Angus breeds which had the lowest CH_4 intensity; to 0.85kg which was from the Charolais breed that had the highest CH_4 intensity in South Africa. This is a difference of 44%, which gives an indication that small to medium frame breeds are more efficient in terms of methane production as compared to large frame breeds.

Because of the low CH_4 intensity of the Afrikaner, Bonsmara, Angus, Brahman and Brangus breeds, they can be regarded as environmentally friendly. The Nguni and Hereford have medium or fair CH_4 intensities, while, the Charolais and Simmentaler have high CH_4 intensities and may be regarded as environmentally unfriendly. It is surprisingly that the Nguni had such a high, CH_4 intensity since it is the most fertile of all the breeds. However, it should be taken into account that since the Nguni was the smallest breed a total of 147 cows with calves could be kept on the 1200ha farm and these cows and calves produce large quantities of methane. In addition, the weaning weight of the calves are very low. The bottom line is that less kg of meat is produced from the farm.

In order to compare the results from this study with results from the literature the methane intensity was converted to the carbon dioxide equivalent (CO_2e). This was done by multiplying the CH_4 value with its global warming potential (GWP) (Brander, 2012). The GWP of CH_4 was taken as 23 times that of CO_2, as derived by Scholtz *et al*. (2023). The average CH_4 intensities for low, medium and high intensity breeds were 0.60 kg, 0.66 kg and 0.79 kg, respectively.

Research conducted in Europe has calculated the carbon footprint of beef production as follows: 11.6 kg CO_2e per kg LW for weaner production systems in Ireland and 8.6 to 15.6 kg CO_2e per kg LW for dairy and weaner production systems throughout Europe (Cederberg & Stadig, 2003).

In Australia, Ridoutt *et al*. (2011) looked at six beef cattle production systems, where animals were grazed on improved pastures and finished on feedlot, where the estimated values of carbon footprint ranged from 10.1 to 12.7 kg CO_2e per kg LW. A value of 22 kg CO_2e per kg LW was found in Brazil, according to Cederberg *et al*. (2011). The comparatively high value of CO_2e is mostly caused by the lower rate of weight gain in cattle, which therefore necessitates a longer time until slaughter which is 3 to 4 years.

The results of this study range from 13.8 to 18.2 kg CO2e per kilogram LW, while the values from the literature that can be compared with them range from 8.6 to 15.6 kg

CO_2e per kg LW. This suggests that the study's findings are consistent with those found in the literature. It should be noted that no comparable research has been done in South Africa as of yet.

4.4 The blue water calculations

The same principles used to calculate the breed and herd statistics of methane production (**table 4.1 and 4.2)** were applied in calculating the blue water footprint of beef in South Africa.

The blue water use intensity was estimated and it is referred to as the water footprint throughout the study. It was estimated as litres (L) of blue water/kilogram (kg) live weight leaving the farm per year. The total blue water used on this farm was calculated as follows:

Water use per annum was 16 425 litres/year/LSU multiplied by 200 LSU's which was equals to 3 285 000 kilolitres (kl) (200LSU's x 16 425 L = 3 285 000 kl).

Table 4.4 contains the information needed to calculate the blue water use intensity. In the case of the Nguni, for example, the total kg of weaner calves was 125 calves x 155 kg weaning weight = 19 375 kg of weaner calves. Likewise, the total kg of culled cows was calculated as 8 074 kg (20 cows x 367 kg). The total kg live weight that can leave the farm was then 27 499kg (19 375 + 8 074). In the case of the Nguni the blue water intensity will be:

3 285 000 kl of water used per annum / 27 499 kg of live weight leaving the farm = 120kl/kg.

The blue water use intensity was estimated and can also be referred to as the water footprint. The blue water use intensity of the 9 diverse cattle breeds is presented in Table **4.4.**

Table 4.4: Information needed to calculate the blue water use intensity

Genotypes	Number of weaner calf surplus (n)	Weaning weight (kg)	Total weight of weaner calf (kg)	Number of culled cows (n)	Cow weight (kg)	Total weight of culled cows (kg)	Total weight live weight off farm (kg)	Water use intensity (kl/kg)
Breed 1 – Afrikaner	115	191	21 965	20	467	9 340	31 305	105
Breed 2 – Nguni	125	155	19 375	22	367	8 074	27 499	120
Breed 3 – Bonsmara	105	217	22 785	18	503	9 054	31 839	103
Breed 4 – Angus	102	219	22 338	18	515	9 270	31 608	104
Breed 5 – Hereford	98	204	19 992	17	540	9 180	29 172	113
Breed 6- Brahman	101	214	21 614	18	520	9 360	30 974	106
Breed 7 – Brangus	107	203	21 721	18	488	8 784	30 505	108
Breed 8 – Charolais	66	232	15 312	11	630	6 930	22 242	148
Breed 9 – Simmentaler	77	241	18 557	13	553	7 189	25 746	128

Using the simulations described, the blue water use intensity varied from 103 to 148 kilolitres per kilogram live weight (Kl water /kg live weight) leaving the farm. The water use intensity of small and medium frame breeds such as Afrikaner, Bonsmara and Angus are low, in contrast to the large frame breeds (Charolais and Simmentaler) that have high water use intensities.

The results of the simulations in **Table 4.4** clearly shows that the water footprint per kilogram of live weight leaving the farm differed greatly between various breeds. The Afrikaner, Bonsmara and Angus had a lowest blue water use intensity of between 103 to 105 kl/kg live weight leaving the farm, while the Charolais had the highest blue water use intensity of 148kl/kg live weight. When other breeds are compared to the Afrikaner, Bonsmara and Angus, the blue water use intensity of the Hereford, Brahman and Brangus was 10% higher, while that of the Nguni, Simmentaler and Charolais were, 20%, 30% and 50% higher, respectively.

These results have been compared with those from Junior and Dziedzic (2021) and there was a significant differences, in which the blue water footprint was calculated by dividing the total amount of water used for irrigation services by the final live weight of the cattle at the time of slaughter. This study was carried out utilizing water resources in the production of beef in the amazon biome in Brazil. The total water footprint for beef cattle was 13 637 L/kg for bulls considering a 500kg weight at the time of slaughter while for cows it was 13 667 L/kg live weight. Likewise, the water footprint calculations of this study seems to be very low when compared to the studies of Mekonnen and Hoekstra (2012) who found the global water footprint for a kilogram of boneless beef to be between 15,415 L/kg and 17 387 L/kg in their global assessment of the water footprint of farm animal products. However, when the blue water footprint was estimated for cows, the water consumed was 154 L/kg live weight, while for bulls it was 95.63 L/kg live weight leaving the farm, respectively (Junior and Dziedzic, 2021). These figures are more consistent with the current study's calculations, which showed that the water footprint of live weight leaving the farm ranged from 103 to 148 kl/kg. There is a scarcity of research on the water footprint of cattle production in South Africa. Even though the country is well-known for producing large amounts of beef, not a lot of research has been done to assess the water footprint in extensive systems.

4.5 The effect of a 10% change in each of the component traits on the carbon and water footprint.

The economic values for improvement in cow efficiency traits depend on the phenotypic values of the traits. In the estimation of such values, Amer *et al*. (1996) used changes of 5% and 10% in the traits to estimate the economic values. Jordaan (2016) demonstrated that in four landrace breeds of South Africa, the cow productivity increased by between 10% and 18.3%. It was thus decided to change each of the components traits of cow efficiency in three breeds that represent the different frame sizes in this study by 10%. The breeds chosen for this study were Afrikaner (small frame). Bonsmara (medium frame) and Simmentaler (large frame).

The results for changes in the carbon footprint, with a 10% change in each of the components traits are represented in **Table 4.5**

Table 4.5: Comparison of methane intensity between different frame sizes of breeds i.e. Afrikaner, Bonsmara and Simmentaler, with a 10% change in each trait.

Frame size	Cow weight (kg)	Calf weight (kg)	ICP (days)	Calving Percentage (%)	Weaning Percentage (%)	Methane intensity ($kgCH_4/kg$)
Small						
Average	467	191	448	77	75	0.60
Cow weight -10%	**420**	191	448	77	75	0.58
Calf weight +10%	467	**210**	448	77	75	0.56
ICP -10%	467	191	**403**	90	80	0.59
Medium						
Average	503	217	414	87	84	0.59
Cow weight -10%	**453**	217	414	87	84	0.57
Calf weight +10%	503	**239**	414	87	84	0.55
ICP -10%	503	217	**373**	98	90	0.58
Large						
Average	553	241	474	70	68	0.73
Cow weight -10%	**498**	241	474	70	68	0.71
Calf weight +10%	553	**265**	474	70	68	0.68
ICP -10%	553	241	**428**	83	73	0.73

The results for changes in the water footprint, with a change of 10% in each of the components traits are represented in **Table 4.6.**

Table 4.6: Comparison of water intensity between different frame sizes for Afrikaner, Bonsmara and Simmentaler breeds with a 10% change in each trait.

Frame size	Cow weight (kg)	Calf weight (kg)	ICP (days)	Calving Percentage (%)	Weaning Percentage (%)	Water intensity (Kl / kg)
Small						
Average	467	191	448	77	75	104
Cow weight -10%	**420**	191	448	77	75	108
Calf weight +10%	467	**210**	448	77	75	98
ICP -10%	467	191	**403**	90	80	102
Medium						
Average	503	217	414	87	84	103
Cow weight -10%	**453**	217	414	87	84	106
Calf weight +10%	503	**239**	414	87	84	96
ICP -10%	503	217	**373**	98	90	102
Large						
Average	553	241	474	70	68	127
Cow weight -10%	**498**	241	474	70	68	131
Calf weight +10%	553	**265**	474	70	68	119
ICP -10%	553	241	**428**	83	73	126

The information in Tables 4.5 and 4.6 are summarized in Table 4.7 to demonstrate the percentage change in the carbon (kgCH_4/kg live weight**)** and water footprint (Kl water/ kg live weight) with a 10% change in each of the component traits.

Table 4.7: The effect of a 10% change in the component traits of cow efficiency on the methane and water intensity for different frame sizes of breeds.

Frame size	**Methane intensity (kgCH4/kg live weight)**		
	Cow weight -10%	**Calf weight +10%**	**ICP -10%**
Small	+3.3%	-6.8%	-1.7%
Medium	+3.3%	-6.8%	-1.7%
Large	+2.7%	-6.8%	-1.7%
	Water intensity (Kl water / kg live weight)		
	Cow weight -10%	**Calf weight +10%**	**ICP -10%**
Small	+3.8%	-5.8%	-1.9%
Medium	+2.9%	-6.8%	-1.0%
Large	+3.1%	-6.3%	-1.0%

From **Table 4.7** it can be seen that a 10% increase in calf weaning weight has the largest positive effect on both the carbon (lower methane intensity) and water (lower water intensity) footprint at the farm gate. Surprisingly fertility, as measured by the ICP, has the smallest effect.

These results indicate that an increase in calf weaning weight will have the biggest effect on both a reduction in methane production and blue water use, whereas a decrease in ICP (increase in fertility) will have the smallest effect. The fact that a decrease in cow weight resulted in an increase in methane intensity was at first surprising. However, it should be noted that if cow weight decreases, the kg of live weight from the culled cows leaving the farm is also less.

These results are in contrast with that of Scholtz *et al.* (2016) who reported that ICP had the biggest effect on cow efficiency and depending on the frame size its contribution varied between 44% and 51%. He also indicated that cow weight had the smallest contribution which varied between 17% and 24%, while the contribution of calf weight was very stable and varied between 32% and 33%. However, it should be noted that these results looked at changes in cow efficiency and not methane and blue water footprints.

The study's findings are consistent with those of Jordaan *et al*. (2021), who found similar results in their investigation of four landrace breeds. They observed that the Drakensberger cow productivity improved despite the phenotypic rise in Mature Cow Weight (MCW) (+8.5 kg). Overall, cow productivity has increased by an impressive 14.2%. The MCW increased by 17.5 kg in the case of the Bonsmara. On the other hand, the ICP dropped by 17 days, which improved cow output by 10%. The output of Nguni cows rose by 10.4% in this instance. This increase is the outcome of the decline in MCW and ICP, while there was no discernible change in 205days weaning weight (WW205). Very limited information is available on the environmental impact of changes in the component traits of cow efficiency and more research on this is recommended.

The information on Table 4.5 and 4.6 is summarized in Table 4.8 to demonstrate the estimated methane intensity and water footprint of the diverse beef cattle genotypes.

Table 4.8: The methane intensity and water footprint of the diverse beef cattle genotypes

Genotype	Methane intensity (kg methane/kg live weight)	Water footprint (litre water/kg live weight)
Afrikaner	0.60	100
Nguni	0.68	120
Bonsmara	0.59	100
Angus	0.59	100
Hereford	0.64	110
Brahman	0.61	110
Brangus	0.62	110
Charolais	0.85	150
Simmentaler	0.60	130

CHAPTER 5: GENERAL CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this study the simulations that were done showed that the estimated carbon footprint of beef in South African varies from 0.59 $kgCH_4$ to 0.85$kgCH_4$ (**Table 4.3**). However, it is indicated that with a 10% change in the different component traits, the methane intensity can be to 0.55 $kgCH_4$ to 0.75 $kgCH_4$ (**Table 4.5**) per kg live weight leaving the farm. Likewise, the blue water use intensity between different frame size breeds ranged from 103 kl to 148 kl (**Table 4.4**) of water per kg live weight leaving the farm while the range is from 96 kl to 131 kl (**Table 4.6**) when 10% change in the component was simulated.

Table 4.7 showed a decrease in cow weight had a negative effect on both water and methane intensity, indicating that the adoption of a 10% adjustment had no detrimental effects on CW. The ICP of all frame sizes decreased by 45–47 days (1.7%–1.9%) when ICP was included; because the projected fertility was higher.

The CW saw a 47 kg (3.3%) gain in the case of the small frame breeds. Though there was a notable shift in WW of 6.8% (19 kg), this rise is the consequence of the 10% decrease in both CW and ICP. On the medium frame breeds, CW also increased by 3.3%. In contrast, the ICP reduced by 45 days (1.7%), leading to an improvement in WW of 6.8%. Furthermore, it is clear from looking at all the different frame sizes that a shorter ICP (better fertility) increases productivity while lowering the carbon and water footprint of beef.

However, this study contradicts the existing published evidence that finds cattle to be a major contributor to methane emissions and high water use. Given that this study did not take into account the different production systems, the breed composition of the commercial cattle, and other production phases such as feedlots and abattoirs, when calculating the carbon and water footprint based on kilograms of live weight leaving the farm, methanogenesis and water consumption was found to be low.

Looking at water usage, it should be noted that the blue water use intensity is more relevant for beef cattle as it is the water used daily to raise cattle. Therefore, to accurately estimate the water footprint of beef, it is essential to conduct a full life cycle analysis for all production phases. The effects of production system, weaning rate, and replacement rate all affect the carbon and water footprint of beef. The results of this study provided valuable new insights into the differences between different cattle breeds in terms of the carbon and water footprint. Beef producers can use this information and simulations to determine which breeds are improving environmental management by comparing the carbon and water footprints of different breeds. Livestock farms, in particular are complex systems with different interacting components including soils, crops, feeds, animals and manure, and the approaches that best reduce GHG emissions will depend on local conditions necessitating appropriate mitigations. Moreover, to accurately estimate the water footprint of beef, it is essential to conduct a full life cycle analysis.

5.2 Recommendations

The information from this study, together with the simulation programme, can be used to develop a model that can estimate the farm-gate carbon and water footprint for different production systems (communal, emerging and commercial), different breed types, and levels of production. The financial aspects and benefits of farming with different breeds types, structured crossbreeding and the possible differences in carbon sequestration should be considered in future studies.

In South Africa beef is produced through feedlots, from commercial grass-fed to communal (small scale) production systems. The factors that influence the carbon footprint (methane intensity) in these different production systems should be researched and quantified.

In South Africa (and many other countries) there is limited information on the total water footprint for different beef production systems. This encompass the blue water (water consumed by animals), the green water (calculated from the water use efficiency of the rangeland), the “feedlot feed” water (water used to produce the feedlot feed) and the grey water (from feedlots and abattoirs). Research that quantify the water footprint and water use efficiency of the total beef production system in South Africa is needed.

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